Jurnal Teknologi

Full Paper

APPLICATION OF NANOTECHNOLOGY IN ASPHALT BINDER: A CONSPECTUS AND OVERVIEW

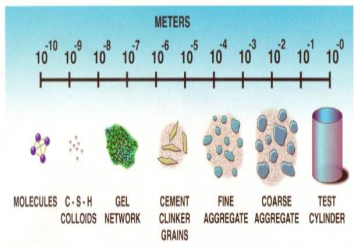
Wan Nur Aifa Wan Azahar[a], Mastura Bujang[a], Ramadhansyah Putra Jaya[a*], Mohd. Rosli Hainin[a], Md. Maniruzzaman A. Aziz[a], Norzita Ngadi[b]

[a]Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Department of Chemical Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Article history
Received
30 April 2015
Received in revised form
27 August 2015
Accepted
1 September 2015

*Corresponding author
ramadhansyah@utm.my

Graphical abstract



Abstract

Nowadays, the nanotechnology is widely applied in pavement engineering in order to improve the properties of materials and their performance. Nanotechnology can be considered as the measurement on nanometer scale that affects the material used in pavement due to its unique characteristic. Therefore, this new technology might indirectly solve the current pavement construction problems. The application of nanotechnology in enhancing the performance of fresh bitumen in term of the longevity and durability has been proven by a lot of previous studies and researches. Literatures have been reviewed and summarized critically to give an overview about the role of nanotechnology in improving pavement material properties. There are some concerns in the application of nanotechnology that needs to be addressed regarding to the safeties of these nano-materials in term of human health.

Keywords: Nanotechnology, nanometer scale, nano-materials

1.0 INTRODUCTION

The concept of new technology, named nanotechnology needs to be addressed critically in order to reduce the use of natural resources and promote an environmental practice in the highway industry. This technology could develop a modified or even a new property of materials. Nanotechnology actually involves with a microscopic scale which is 1nm = $1x10^{-9}$m [1, 2]. Besides, nanotechnology also can be applied in any stages such as design, construction or operation and measured in nanometer scale to develop a nano-material, especially in pavement engineering [3]. A study about atomic, molecular and macromolecular sizes with less than 100 nm can be described as a nanoscience [4]. Recently, there are two main aspects in the nanotechnology evaluation, which are the properties and production of materials, either modified or current. This technology is considered as an essential method in improving the performance of materials in highway engineering.

2.0 MATERIALS WITH NANOTECHNOLOGY

Due to the small particle size, nanotechnology focuses on nano-materials with unique functions in term of strength, durability, high speed of construction, and environmental impact reduction [5]. Figure 1 shows the scale of particles in road materials that might improve the performance of highway construction at macro-functional level. Their characteristics and behavior will be affected when nano-materials are implemented in

the pavement structures. Hence, the properties or physical behavior of nano elements will give a better result compared to the current size of materials [6].

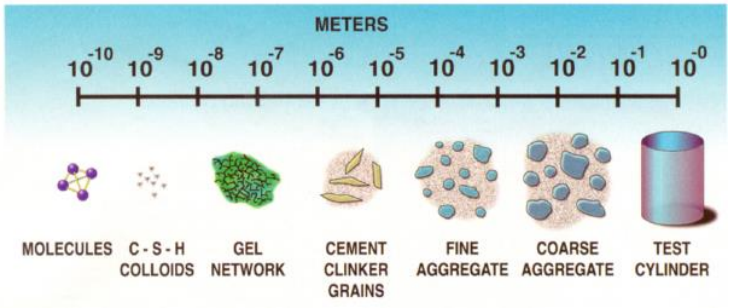


Figure 1 Scale of particle for road material [5]

There were a lot of researches funded by The Federal Highway Administration (FHWA) that encourages the application of nanotechnology in highway industry. They have proven that long lasting service life with an application of nanotechnology in highway at nano-scale can be developed and achieved. According to the previous studies, any materials that have undergone the nano tests can ensure their optimal usage and give long term effects in structural function such as [7]:

i. Both environmental and traffic loads can be resisted;
ii. Energy will be produced and transferred into a pavement layer;
iii. Relationship between vehicle-pavement can be improved due to the conditions of pavement

2.1 Nano-Material Substitution in Pavement

Bitumen is a crucial material used in pavement, in fact its mechanical behaviors and physical properties are measured in microstructure and micro-nano scale [8]. The usage of nano-materials in pavement need to be explored in depth either in characteristics or physical properties so that materials with nanotechnology application can be obtained. In addition, nano-material with small scale gives high functional density, large surface area, high sensitivity, catalytic effect, and high strain resistance [9]. When nano-materials, which is in the form of powders, soluble, or fibre added into the bitumen portions, it will categorize as a nano-material too [10].

2.1.1 Asphalt Binders

According to the research done by Kotlyar *et al*. [11], bitumen is a nano-sized solid which consists of aluminosilicate clays coat with toluene, which is an insoluble organic material. Bitumen is defined as a complex composition which comprises of hydrocarbon in solid and liquid particles, known as asphaltenes and maltenes. Besides, the critical shear rate is depending on an intrinsic condition of bitumen [12]. The information about binding between bitumen and aggregate should be improved in the nanotechnology processes which is influenced by the usage of TiO_2 as an intervention against UV [13]. Hence, the elasticity of nano-clay in modified bitumen will increase when nano-clay is added into the binder, meanwhile the mechanical energy dissipation is lower compared to fresh bitumen [14]. Based on previous studies, nano-clays can improve the maturity resistance of bitumen in both short and long term [15].

3.0 CHARACTERISTICS OF NANO-MATERIAL

It is important to understand the characteristics and behavior of nano-sized materials, specifically in pavement engineering field. Most of the equipment's for testing are designed only for a macro scale measurement, hence it is essential to introduce new instruments that can be used to measure the nano-scale materials such as Atomic Force Microscope (AFM), Scanning Electron Microscope (SEM), Transmission Electron Microscopy (TEM), and Scanning Transmission Electron Microscopy (STEM). The suitable nanotechnology equipment's for evaluating a bulk structure in thin samples are TEM and STEM, whereas SEM or AFM will be used to obtain the nano-scale characteristics of pavement. SEM and AFM are the nanotechnology instruments that able to see and manipulate nano-sized particle until it can be discovered in a size of 40 to 50 mm.

3.1 Scanning Electron Microscope (SEM)

Figure 2 shows a layout of SEM that can be used to analyze the surface and subsurface images on nano-particles. It is essential to understand their particles and behavior in order to bond them with macro properties. Through scanning process, the image of samples will be produced with a high-energy beam of electrons. Then, the information about surface structure can be achieved when the electrons interact with the atoms.

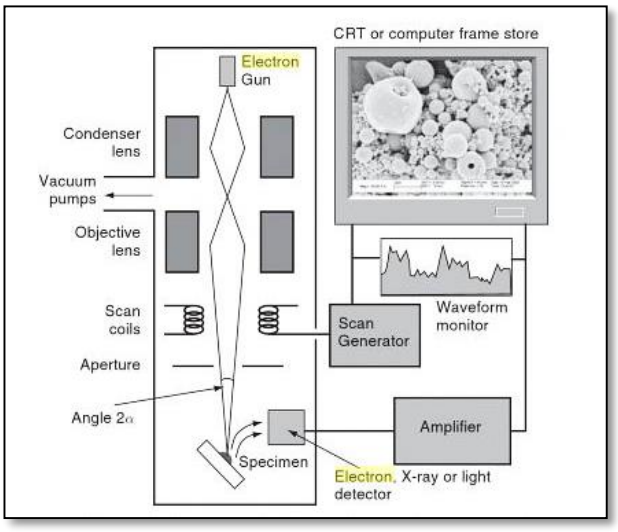


Figure 2 Scanning Electron Microscope (SEM) Layout [16]

3.2 Atomic Force Microscope (AFM)

Figure 3 shows the layout of AFM that is used to analyze surface properties of samples by using atomic forces. A sharp probe and a cantilever will scan the surface of samples. Based on Hooke's Law, the force between the probe and samples will be produced in a deflection of cantilever when the probe is placed into a sample surface. There are several forces that will be measured in AFM include Van der Waals force, mechanical contact force, magnetic forces, capillary forces, chemical bonding, and electrostatic forces.

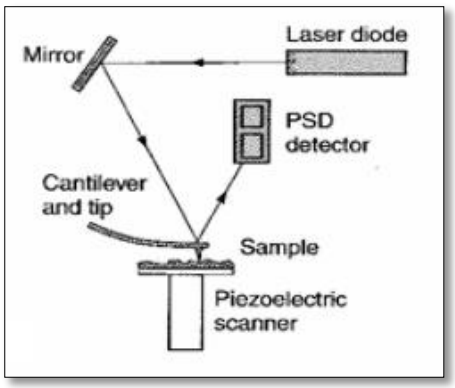


Figure 3 Atomic Force Microscope (AFM) Layout [16]

3.3 Application of SEM and AFM in Bitumen

According to Muniandy [17], the differences between Malaysian and traditional cellulose fibers used in Stone Mastic Asphalt (SMA) mixtures can be evaluated by using SEM which is used to measure the microstructure materials. It shows that the thickness of Malaysian fiber scales is less than 500 µm compared to the traditional fibers which are approximately 50 µm. In Stulirova and Pospisil studies [18], the procedures to conduct SEM by using binder mixtures are discussed and due to the liquid and oily fraction, maltenes will be removed from the samples during SEM analysis [19]. The left portions of bitumen, which is asphaltenes will be examined because SEM can evaluate the changes in this structure only. Besides, the performance of recycled cemented base pavement layer with bitumen emulsion as a stabilizer were tested by using Accelerated Pavement Testing (APT) [20]. Then, SEM will be used to make a comparison between carbonated and un-carbonated stabilized materials. Figure 4 shows the appearance image of bitumen and cementitious bond which is detected in the base materials.

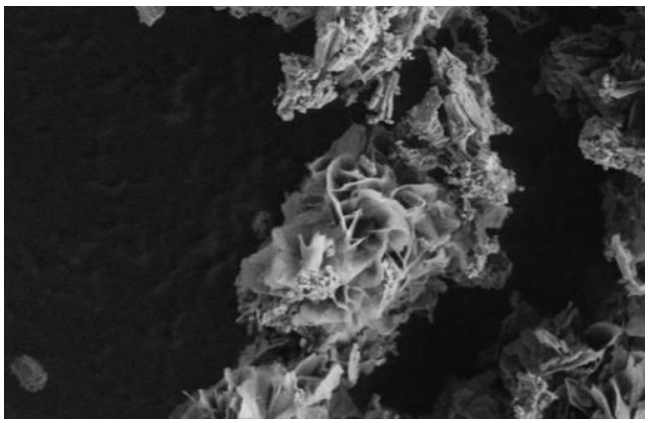


Figure 4 Location of bitumen and cement reaction crystals in SEM images [20]

The characteristics of bitumen such as surface morphology and its constituents can be described by using AFM method based on Pauli *et al*. studies [21]. The asphaltenes behavior in asphalt binder and their bonding characteristic with aggregates can be enhanced by using the results obtained from AFM. In addition, the AFM technique can be also used to analyze the structural morphology of aged bitumen that contains crumb rubber [22]. According to Masson *et al*. [23], an AFM face detector is able to divide and categorize a bitumen elements into three groups based on their phases and their elastic stiffness in the pavement can be evaluated too [24]. Figure 5 shows the images of surface morphology of aged bitumen at different three temperatures, which are 40°C, 80°C, and 140°.

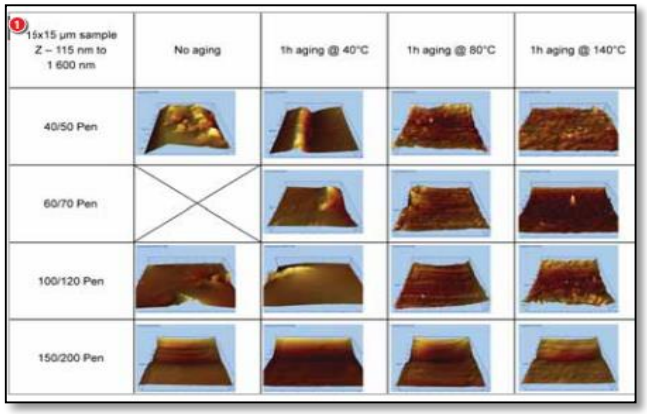


Figure 5 Surface morphologies bituminous at three different temperatures [25]

4.0 CONCERN AND ISSUES

A short summary of challenges and problems that affect the application of nanotechnology in highway industry are discussed in this section. It is necessary to understand the effects occur, especially in toxicity and health problems when the nanotechnology is implemented in pavement structures.

4.1 Issues of Health and Toxicity

Based on several numbers of studies, the usage of nano-materials in any products could cause serious diseases and give side effect to human body and ecological system due to their larger surface area per mass unit. Grassian *et al*. [26] have reported the effect of TiO_2 particle inhalation, which is one of the nano-material with a primary particle size between 2 and 5nm could cause lung inflammation effect [27-31]. In addition, the nanotoxicity risks and effects are depending on the type of nano-particles and concentration volume characteristics. Mesothelioma is a disease that causes malignant cancer cells that form within the chest, abdomen, or heart and can easily spread in high usage of carbon nanotubes (CNTs). It is important for the users to reduce the amount of hazards from nano-particles during the design and construction. Therefore, there are five rules that can be implemented to mitigate these health exposures as stated [32]:

i. Size, surface and structure of the nanoparticle should be changed so that the desired product functionality is preserved while reducing the potential of nano-particle at the same time;
ii. Alternate materials should be identified to replace the hazardous nano-particle;
iii. Functionalization (deliberately bond molecules to nano-particles to alter the conditions in a manner that desired product properties are maintained, but reduce or eliminated the hazard potential of the nano-particle);
iv. The potentially hazardous nano-particle should be enclosed within a material that is less hazardous through encapsulation process;
v. The choice of using smaller quantities of the hazardous nano-particle in the product should be evaluated while maintaining product functionality

5.0 CONCLUSION

The application of nanotechnology in bituminous binder proves that the pavement can achieve high performance results in term of strength and durability based on the previous researches. Through this technology, nano-materials can be produced and existing materials can be improved in order to control the use of natural resources which indirectly could achieve sustainable development. There is a lot of nanotechnology research needs to be conducted especially in bituminous binder due to its limitations and not widely explored. However, nano-materials might affect the biological and ecological systems

due to their size and particles which can cause health problems. Hence, a regulation related to these problems should be introduced in order to mitigate the health risk matters.

Acknowledgement

The support provided by Malaysian Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (UTM) in the form of a research grant number Q.J130000.2522.09H67 and Q.J130000.2422.02G84 for this study is very much appreciated.

References

[1] Drexler, K. 1981. Molecular Engineering: An Approach to the Development of General Capabilities for Molecular Manipulation. *Proc Natl Acad Sci*. 78(9): 5275-5278.
[2] Totey, S. and Deb, K. D. 2010. *Stem Cell Techmologies, Basics and Applications List of Contributors. Stem Cell and Regenerative Medicine–The Evolving Story, Access Engineering*. Mc Graw Hill Professional Publication.
[3] Kelsall, R. W., Hamley, I. W. and Geoghegan, M. 2005. *Nanoscale Science and Technology*. John Wiley and Sons Ltd. Chichester.
[4] Ravichandran, R. and Sasi Kala, P. 2006. Nanoscience and Nanotechnology: Perspectives and Overview. *School Sci*. 43-49.
[5] Mann, S. 2006. *Nanotechnology and Construction*. European Nanotechnology Gateway-Nanoforum Report, Institute of Nanotechnology.
[6] Wang, K. 2003. Size Effect in the Cell Response to Substances in Solid Phase. *China Particuology*. 1(1): 3.
[7] FHWA. 2009. *Nano-Scale Approaches for Highway Research*. Exploratory Advanced Research Program, Publication No. FHWA-HRT-10-033 HRTM-04/01-10(1M)E.
[8] Partl, M.N., Gubler, R. and Hugener, M. 2003. Nano-science and-Technology for Asphalt Pavement. *Proceeding 1st International Symposium on Nanotechnology in Construction, Paisley, Scotland*. 343-355.
[9] Teizer, J., Venugopal, M., Teizer, W. and Felkl, J. 2012. Nanotechnology and Its Impact on Construction: Bridging the Gap Between Researchers and Industry Professionals. *Journal of Construction Engineering Management*. 138(5): 594-604.
[10] Steyn, W. J. M. 2011. Applications of Nanotechnology in Road Pavement Engineering. *Nanotechnology in Civil Infrastructure*. Springer-Verlag Berlin Heidelberg. 49-83.
[11] Kotlyar, L. S., Sparks, B. D., Woods, J. R., Raymond, S., Le Page, Y. and Shelfantook, W. 1998. Distribution and Types Of Solids Associated With Bitumen. *Petroleum Science and Technology*. 16(1-2): 1-19.
[12] Lesueur, D. 2009. The Colloidal Structure of Bitumen: Consequences on the Rheology and on the Mechanisms of Bitumen Modification. *Advances in Colloid and Interface Science*.145: 42-82.
[13] Liao, G., Huang, X. and Ba Sang, D. 2008. Antiultraviolet Aging and Antithermal-Oxygen Aging Tests of Asphalts Adapting to Environment of Tibetan Plateau of China. *Proc. 87th Transportation Research Board Meeting, Washington D.C.*
[14] Jahromi, S. G. and Khodaii, A. 2009. Effects of Nano-clay on Rheological Properties of Bitumen Binder. *Construction and Building Materials*. 23: 2894-2904.
[15] Van de Ven, M. F. C., Molenaar, A. A. A., Besamusca, J. and Noordergraaf, J. 2008. Nanotechnology for Binders of Asphalt Mixtures. *Proceeding Road for Life, Copenhagen, Denmark*. 842-853.
[16] Kelsall, R. W., Hamley, I. W. and Geoghegan, M. 2004. *Nano-scale Science and Technology*. John Wiley and Sons Ltd., Chichester.
[17] Muniandy, R. 2002. Laboratory Evaluation of Malaysian Cellulose Oil Palm Fiber for use in Stone Mastic Asphalt Mixes. *International Journal of Pavements*. 75(3): 13-21.
[18] Stulirova, J. and Pospisil, K. 2008. Observation of Bitumen Microstructure Changes using Scanning Electron Microscopy. *Road Materials and Pavement Design*. 9(4):7 45-754.
[19] Brownridge, J. 2010. The Role of an Asphalt Rejuvenator in Pavement Preservation: Use and Need for Asphalt Rejuvenation. *1st International Conference on Pavement Preservation.* 351-364.
[20] Steyn, W. J. M. and Jones, D. J. 2006. *Technical Memorandum: HVS testing of N12-19 East, Section 2*. Contract Report CSIR/BE/IE/ER/2007/0001/B, CSIR Built Environment, Pretoria, South Africa.
[21] Pauli, A. T., Branthaver, J. F., Robertson, R. E. and Grimes, W. 2001. Atomic Force Microscopy Investigation of Shrp Asphalts. *Proc. Symp. on Heavy Oils and Residue Compatibility and Stability, 221st National Meeting, American Chemical Society: Division of Petroleum Chemistry, San Diego, California, USA*.
[22] Huang, S. C., Pauli, A. T., Beemer, A. and Robertson, R. E. 2006. Influence of Crumb Rubber on the Fatigue Performance of Asphalt Pavement. *Proceeding 10th Inernational Conference on Asphalt Pavements, ICAP, Quebec City, Canada.*
[23] Masson, J. F., Leblond, V. and Margeson, J. 2006. Bitumen Morphologies by Phase-Detection Atomic Force Microscopy. *Journal of Microscopy*. 221(1): 17-29.
[24] Steyn, W.J.M. 2009a. Potential Applications of Nanotechnology in Pavement Engineering. *Journal of Transportation Engineering.* 135(10): 764-772.
[25] Steyn, W. J. M. 2009b. *Nanotechnology in Pavement Engineering*. Report:CSIR/BE/IE/IR/2009/0098/B, CSIR Built Environment, Pretoria, South Africa.
[26] Grassian, V., OShaughnessy, P., Adamcakova-Dodd, A., Pettibone, J. and Thorne, P. 2007. Inhalation Exposure Study of Titanium Dioxide Nanoparticles With A Primary Particle Size of 2–5 nm. *Environ Health Perspec*. 115: 397-402.
[27] Yu, Y., Zhang, Q., Mu, Q., Zhang, B. and Yan, B. 2008. Exploring the Immunotoxicity of Carbon Nanotubes. *Nanoscale Research Letter*. 3: 271-7.
[28] Liu, A., Sun, K., Yang, J. and Zhao, D. 2008. Toxicological Effects of Multi-Wall Carbon Nanotubes in Rats. *Journal Nanoparticle Research*. 10: 1303-1307.
[29] Poland, C., Duffin, R., Kinloch, I., Maynard, A., Seaton, Wallace W. and Stone, A. 2008. Carbon Nanotubes Introduced Into The Abdominal Cavity Of Mice Show Asbestos-Like Pathogenicity in a Pilot Study. *Nature Nanotechnology*. 3: 423-428.
[30] Donaldson, K. and Poland, C. 2009. Nanotoxicology: New Insights into Nanotubes. *Nature Nanotechnology*. 4: 708-710.
[31] Pacurari, M., Castranova, V. and Vallyathan, V. 2010. Single and Multi-Wall Carbon Nanotubes versus Asbestos: Are the Carbon Nanotubes a New Health Risk to Humans. *Journal Toxicol Environ Health*. 73: 378-395.
[32] Morose, G. 2010. The 5 principles of Design for Safer Nanotechnology. *Journal of Cleaner Production*. 18: 285-289.